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THE WINDS OF BERBERA

Discussion of Observations made under the Supervision of

R. S. TAYLOR, M.B., Ch.B., Principal Medical Officer

By C. E. P. BROOKS, D.Sc.

and

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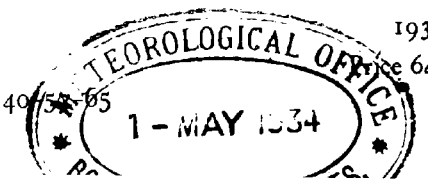

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THE WINDS OF BERBERA

Discussion of Observations made under the Supervision of R. S. TAYLOR, M.B., Ch.B., *Principal Medical Officer*

By C. E. P. BROOKS, D.Sc. and C. S. DURST, B.A.

Acknowledgment.—In presenting this note on the wind regime at Berbera, the authors wish to put on record their deep sense of gratitude to Dr. Taylor, the Principal Medical Officer at Berbera and his assistants, through whose enthusiasm the present series of anemograph and pilot-balloon observations were made. They fully realise the difficulties which are involved in work of this nature, done not only in a trying climate but in addition to the normal duties of a medical officer; but the outstanding interest and value, both scientific and practical, of the records obtained more than justify the labour and expense of obtaining them.

Locality.—Berbera lies on the southern shore of the Gulf of Aden on a narrow strip of land between the sea to the north and the mountains of British Somaliland which reach a height of about 5,000 or 6,000 feet at a distance of some 50 miles south of Berbera. The coast line at Berbera runs approximately east-north-east and west-south-west, but the mountain range lies almost east and west from Cape Ras Hafun on the east to the Abyssinian mountains on the west. These latter mountains descend in a sharp escarpment facing east along a line which follows closely the 40th meridian. On the northern side of the Gulf of Aden the mountains of Arabia rise above Aden to a height of more than 6,000 feet. The physical features are shown in Fig. 1.

The climate of Berbera.—The climate is very hot. The mean annual temperature is 86° F. and from June to September inclusive the mean daily maximum exceeds 100° F. (see Table IV, p. 10). The atmosphere is very dry, especially during the SW. monsoon, and there is very little cloud. The rainfall which is small occurs in occasional short showers, and sometimes " cloudbursts " are experienced. The season with most rain at Berbera is from February to May, but the falls are most irregular; further inland the rainfall is much higher and the season of greatest fall is between April and November.

Berbera is subject to the NE. monsoon between October and May while from June to September the SW. monsoon prevails. Superimposed on these winds are the land and sea breezes, the effects of which are clearly brought out by a table due to Brooks.[1] This table shows that in July and August the south-westerly wind is reported on 98 per cent of occasions in the early morning (often blowing with gale force) while in the evening its frequency has fallen to 29 per cent and on 57 per cent of the evenings calms prevail. During the NE. monsoon season, however, the NE. wind is reported on 98 per cent of occasions at midday, but in the early morning there are calms on 60 per cent of occasions. The

[1] Brooks, C. E. P. The meteorology of British Somaliland. *Q.J.R. Meteor. Soc.* **46,** 1920, p. 434.

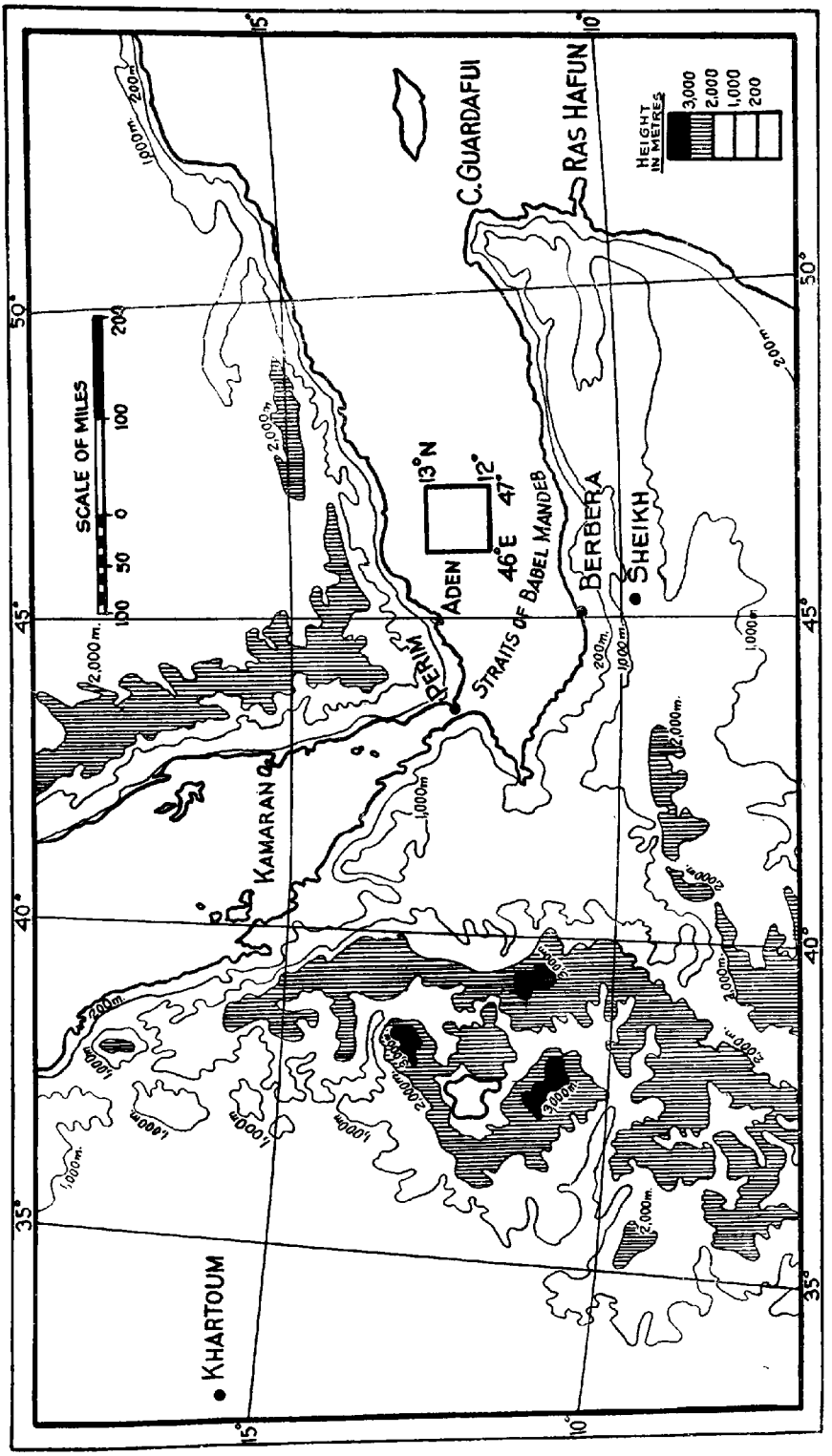
SCALE OF MILES
100 50 0 100 200
HEIGHT IN METRES
3,000
2,000
1,000
200
C. GUARDAFUI
RAS HAFUN
ADEN
PERIM
STRAITS OF BABEL MANDEB
BERBERA
SHEIKH
KAMARAN
KHARTOUM
13°N
12°
47°
46°E
50°
45°
40°
35°
15°
10°

FIG. 1.

annual variation of the wind direction is also shown clearly in the vector diagram illustrated in Fig. 2.

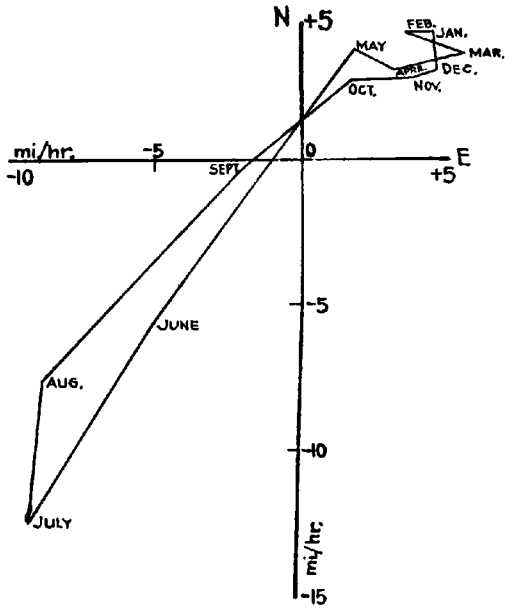

FIG. 2.—Annual variation of resultant wind at Berbera.

Data.—From May, 1931, a Dines pressure-tube anemograph has been working at Berbera. The records from this instrument for a period of two years, up to April, 1933, have been used to obtain mean values of the wind at each hour of the day in order to illustrate the diurnal variation of surface wind.

From April 24, 1931, to the end of July, 1932, observations of upper winds were made almost daily (and on some occasions both morning and afternoon). The number of morning and afternoon ascents in each month is given in Table I.

TABLE I.—NUMBER OF MORNING AND AFTERNOON ASCENTS

		May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1931	a.m. ..	28	31	10	7	24	32	36	27
	p.m. ..	6	15	31	35	13	7	—	5
		Jan.	Feb.	Mar.	Apr.	May	June	July	
1932	a.m. ..	16	22	19	26	20	—	—	
	p.m. ..	17	7	11	3	11	30	18	

The observations (combining morning and afternoon ascents) were summarised in the form recommended by the International Commission for Air Navigation and the results are shown by the wind roses in Fig. 3, which give the frequencies of winds from different directions at the surface and at heights of *1,500, 3,000,*

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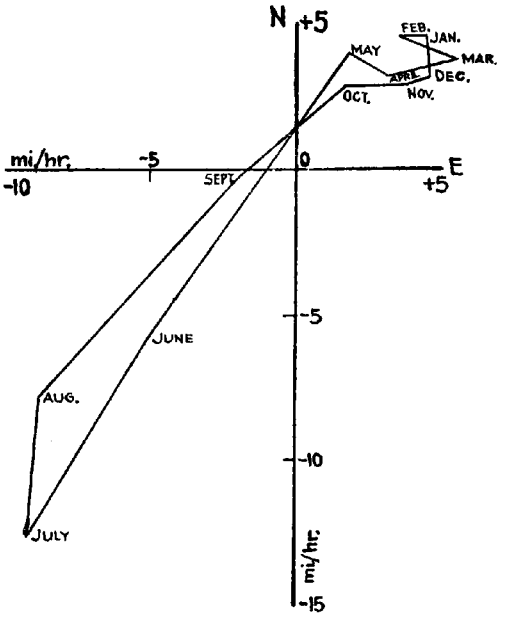

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	p.m. ..	6	15	31	35	13	7	—	5
		Jan.	Feb.	Mar.	Apr.	May	June	July	
1932	a.m. ..	16	22	19	26	20	—	—	
	p.m. ..	17	7	11	3	11	30	18	

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SEASONAL VARIATION OF

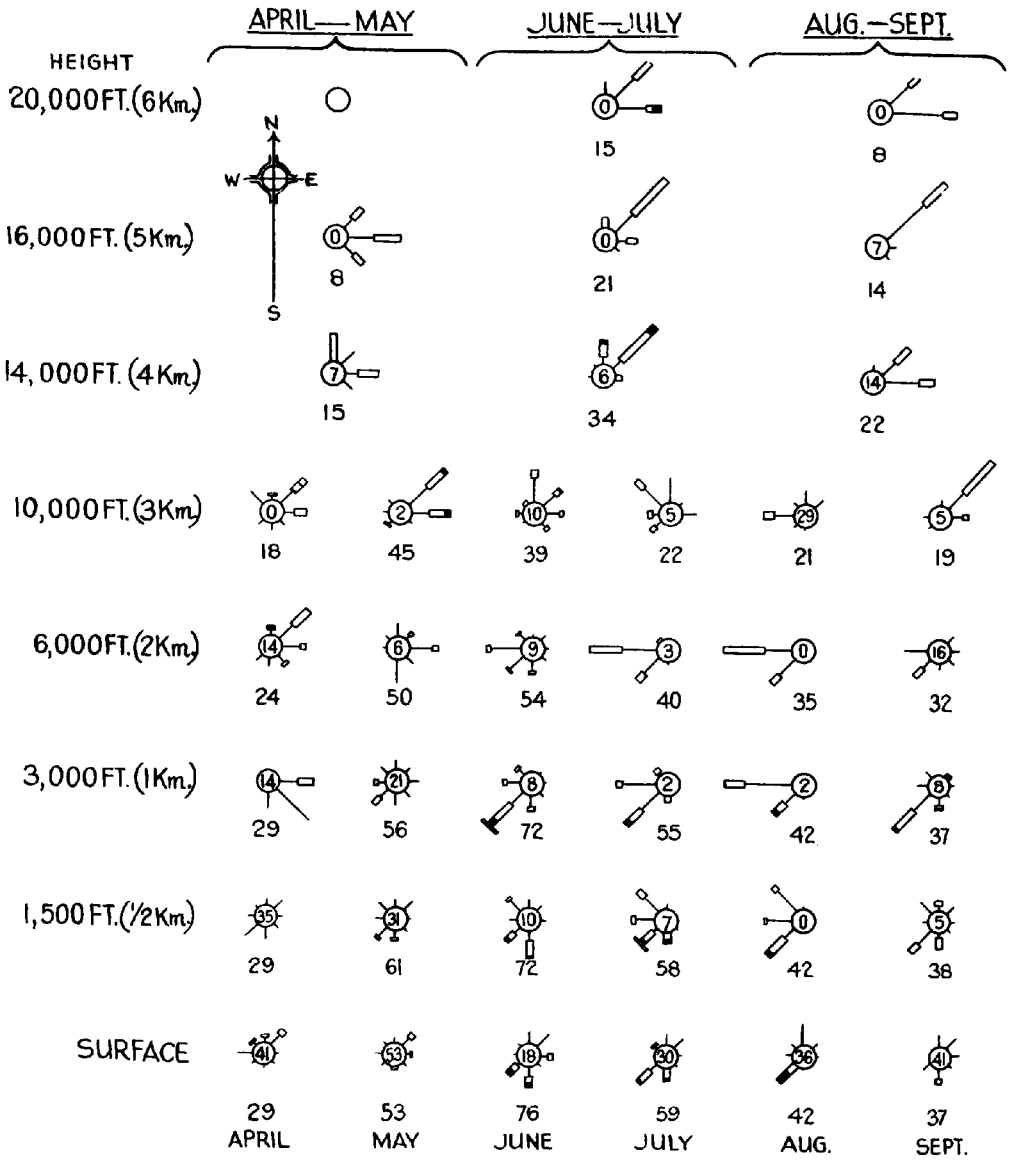
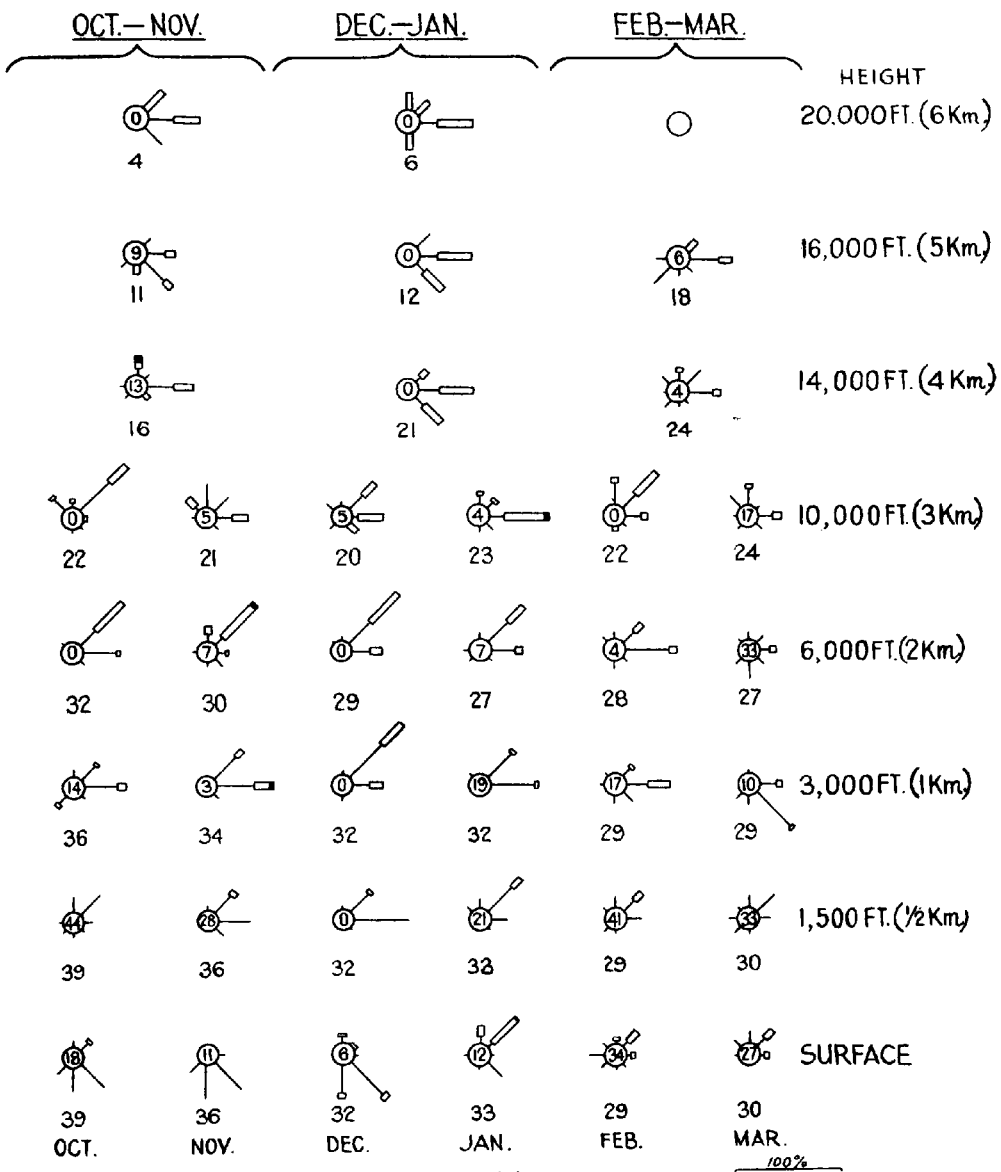


FIG. 3.

THE FIGURES IN THE CENTRES OF THE CIRCLES LESS THAN 4 mi/hr. THE FIGURES BELOW

UPPER WINDS AT BERBERA



DENOTE THE PERCENTAGE FREQUENCY OF WINDS
THE ROSES THE NUMBER OF OBSERVATIONS.

6,000, 10,000, 14,000, 16,000 and 20,000 feet, corresponding to levels at $\frac{1}{2}$, 1, 2, 3, 4, 5, and 6 kilometres.

It is to be noticed that in July and August the number of occasions of morning ascents is small and for this reason there is a decrease in the speed of the SW. monsoon near the surface shown in Fig. 3 which is not representative of the conditions during the morning hours.

These two sets of data bring into evidence (*a*) the remarkable diurnal variation of wind at Berbera and (*b*) the variation of wind with height in the different seasons; though the total flow of air at Berbera, at least at the surface, is almost nil when averaged over the whole year, as may be seen from Fig. 2, in which are plotted the resultant surface winds for each month. The mean for the year falls almost exactly on the origin, which shows that the strong south-westerly flow in June, July and August is just balanced by the north-easterly flow of October to May.

The variation of wind with height at Berbera.—Dealing first with the variation of wind with height, Fig. 3 shows clearly how the winds above Berbera change with the seasons. During the season of the SW. monsoon over the Arabian Sea, June to September, the predominant current in the neighbourhood of Berbera is south-westerly up to about 3,000 feet and may be of great strength; above this height there is a decided westerly flow extending to about 10,000 feet, at which level it merges into a north-easterly current which is very constant and definite in the levels from 10,000 to 20,000 feet. When the SW. monsoon fails this NE. wind appears to penetrate further and further towards the surface and to become more easterly in the levels between 10,000 and 20,000 feet, as is shown in Fig. 3, during the months of October, November and December. The large number of north-easterly winds at the surface in January is due to the majority of observations in that month being afternoon observations, but it is noticeable that in that month and in February, March, April and May, light or very light winds are of great frequency up to 3,000 feet; from this it may be judged that the NE. monsoon, which at that season is blowing over the Arabian Sea, only extends over Berbera as a comparatively weak current, though its depth is considerable, as easterly winds extend in these months up to the greatest heights reached by pilot balloons at Berbera.

The diurnal variation of wind at Berbera.—The anemograms at Berbera show the regular diurnal variation very clearly; two typical days have been selected and described below (the anemograms being reproduced as Figs. 4 and 5). The anemometer head is 88 feet above ground level and 30 feet above the surrounding buildings. It is situated about 40 yards from the seashore. The times used are International Zone Time, 4 hours fast on G.M.T.; local mean time at Berbera is less than 2 minutes slow on Zone Time.

July 20–21, 1931 (*SW. monsoon*).—The SW. wind, which had been blowing all the night of the 19th–20th increasing to a maximum of over 40 mi./hr. (with gusts of 55 mi./hr. at 8h. 30m.), died down gradually till 13h. 30m. with an increasing tendency to instability. Between 13h. 15m. and 13h. 30m. the sea breeze set in quite suddenly and convection suddenly ceased at the surface. At sundown the wind fell calm and at 22h. 30m. the SW. wind once more asserted its sway in a sudden break. On the following morning convection began once more at 9h. 20m. and the sea breeze arrived, with a discontinuity of wind direction as abrupt as a sharp front, at 11h. 45m. after instability had become very great.

December 16–17, 1931 (*NE. monsoon*).—A light southerly wind in the early morning of the 16th died down as convection set in at 9h. 30m. and backing to N. sprang up again at 11h. with considerable instability occurring until 18h. A period of light winds lasted from 20h. to 2h. of the 17th, when the southerly night wind once more became established.

The mean velocity of the surface wind at each hour, irrespective of direction, is given in Table II. The months of the NE. monsoon (October to May) show a well-marked diurnal variation from a minimum in the early morning to a maximum in the early afternoon. During the months of the SW. monsoon (June to August) the diurnal variation is different, the maximum occurring about 9h. and reaching a very high value, and the minimum occurring in the evening about 20h. In the former months the NE. monsoon is reinforced by the sea breeze ; in the latter months the SW. monsoon conflicts with the sea breeze.

Table III gives the vector means (direction and velocity) at each hour of each month. These are clearly illustrated by Fig. 6 where the resultant wind at each hour is indicated by the vector to the intersection of the two axes from the point marked by the hour in question. The average of the whole 24 hours is shown by the arrow to the intersection of the axes from the small circle. It should be noted that the winds are drawn as blowing inwards to the origin. The four " seasons " and the year are drawn separately and all show a well-marked diurnal variation.

The diurnal variation of the surface wind at Berbera illustrated in Fig. 6 is remarkable. The two periods, December to February and September to November, are closely similar. From 11h. to 13h. the wind is northerly and of increasing strength. From 14h. to about 21h. the wind veers steadily from N. towards E., increasing in velocity until 15h. or 16h., after which it commences to fall off. After a period of light winds near midnight a definite land breeze sets in from S., reaching a maximum between 6h. and 8h. and rapidly falling off to calm after 9h. This course of events represents very well the normal effect of land and sea breezes superposed on a moderate north-easterly current. In March to May the diurnal variation is generally similar but the

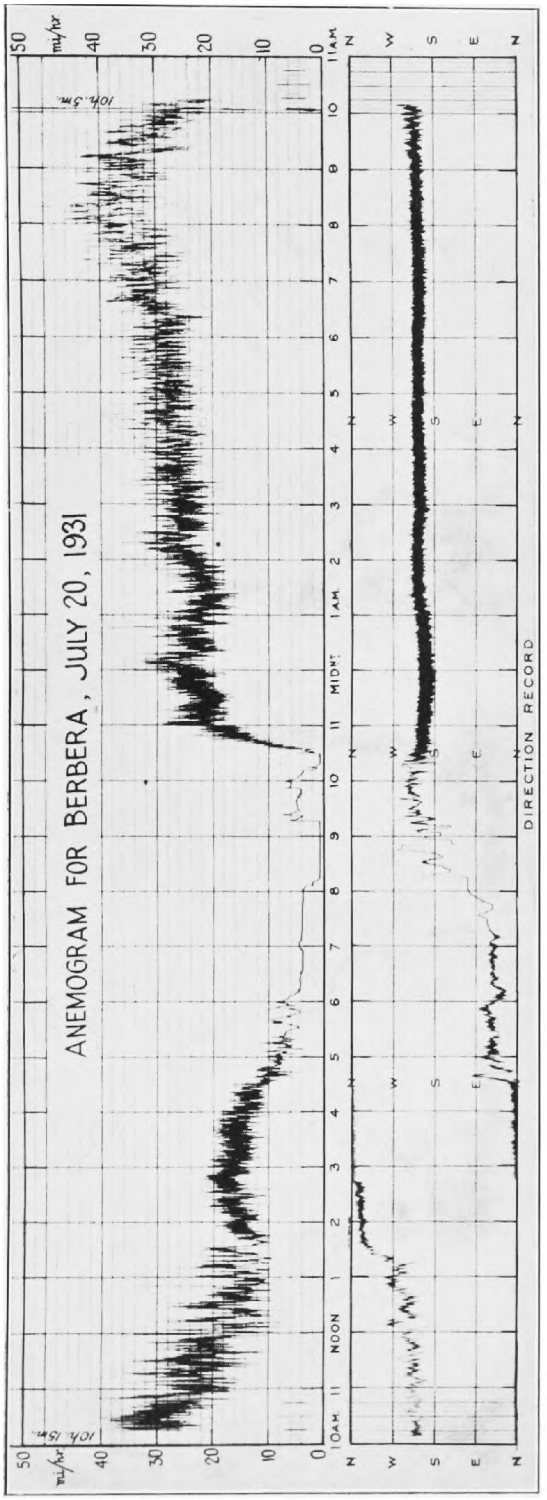


FIG. 4.—Anemogram for Berbera, July 20–21, 1931.

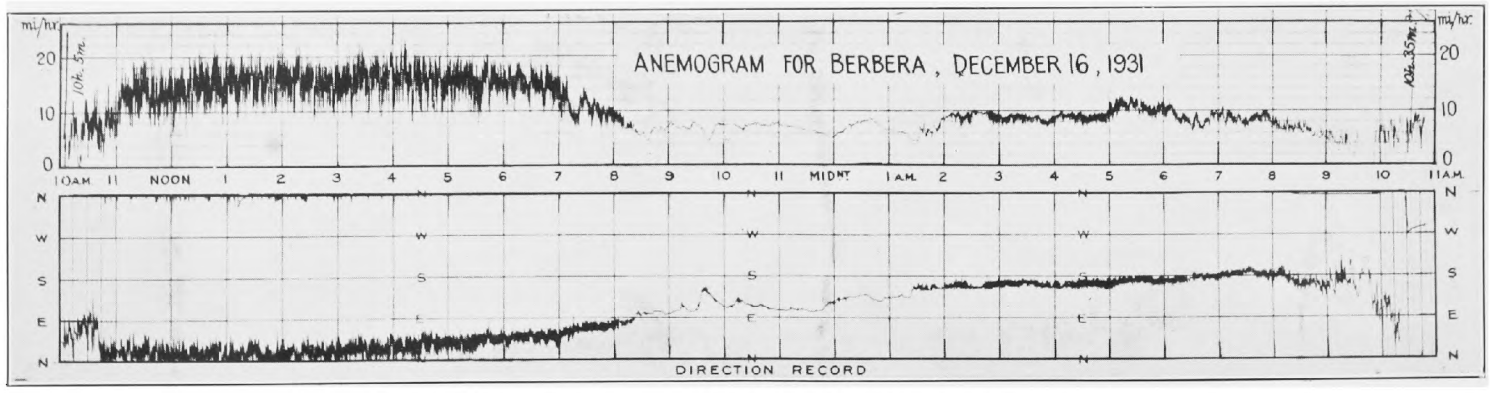


FIG. 5.—Anemogram for Berbera, December 16–17, 1931.

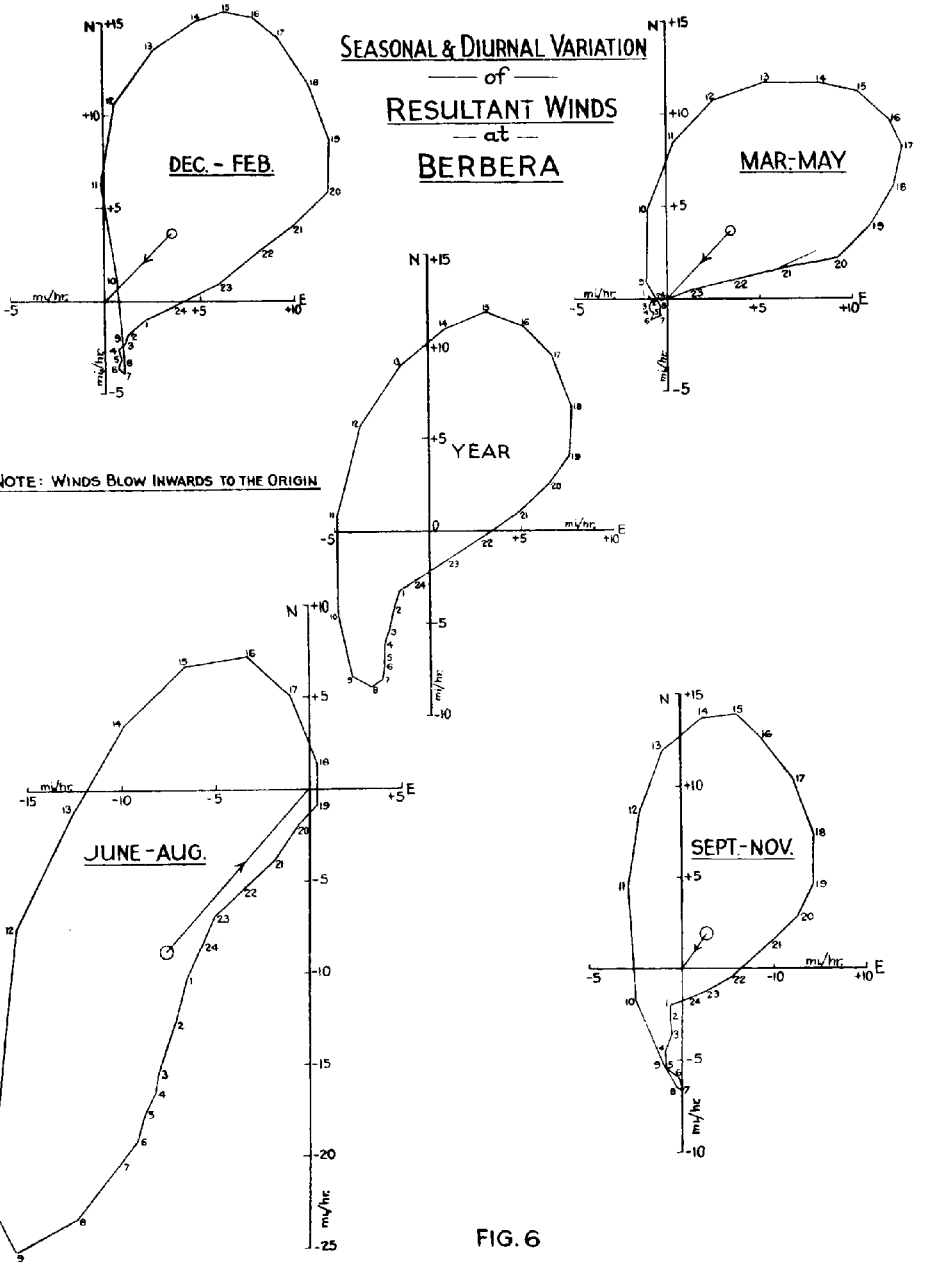


FIG. 6

(868) P. 4280 2478 675 4/33 G 921 C8 RL

DIURNAL VARIATION OF UPPER WINDS AT BERBERA

JULY 1-16 & AUG. 17-29, 1931.

DECEMBER 1931 & JANUARY 1932

6h.30m. to 8h. LOCAL TIME	16h.30m. to 18h. LOCAL TIME	7h.45m. to 9h.15m LOCAL TIME	15h.45m. to 17h.15m LOCAL TIME	
4	14	10	5	6,000 FT.
5	14	11	7	5,000 FT.
8	15	11	9	4,000 FT.
13	15	11	10	3,000 FT.
15	15	11	11	2,000 FT.
15	15	11	11	1,500 FT.
14	15	11	11	1,000 FT.
15	15	11	11	SURFACE

N, W, E, S

The figures in the centres of the circles denote the percentage frequencies of winds less than 4 mi/hr., The figures below the roses the number of observations.

SCALE 100% mi/hr 4-15 16-31 32-47 over 47

FIG. 7

nocturnal land breeze is almost completely suppressed, being replaced by a period of calm from 23h. to 9h.

The diurnal variation for the period June to August presents a different picture. The general direction of the wind is now from SW. instead of from NE., and the wind blows on shore for only a few hours during the afternoon. This on-shore wind may be a true sea-breeze effect but the magnitude of the variation between 9h. and 16h. (nearly 35 miles per hour) is very great to be an effect solely of diurnal heating and cooling.

In Fig. 7 is shown the extent to which the diurnal variation extends vertically during the SW. and the NE. monsoon seasons. The data used in the construction of this figure were 15 morning ascents and 15 evening ascents either on the same or adjacent days during the periods, July 1–16 and August 17–29, 1931, as representing the SW. monsoon, and 11 morning and evening ascents during December and January, as representing the NE. monsoon.

In both cases it is seen that there is a definite diurnal variation up to between 3,000 and 4,000 feet from the surface. The magnitude of the variation is, however, very much greater during the SW. monsoon season than during the NE. monsoon.

The NE. monsoon is increased by the sea-breeze effect during the afternoon from the surface up to 2,000 feet, while at the 3,000-foot level there is a decrease in the strength of the monsoon which probably represents the return current from land to sea. In early morning the NE. monsoon is retarded by the land-breeze effect between 2,000 feet and the surface and results most frequently in a light easterly wind. This would appear to be a normal effect of land and sea breezes superposed on a north-easterly wind.

During the SW. monsoon season the diurnal variation above the surface is less easy to explain. In the mornings (at about 6.30 to 8 a.m. local time) before the warming up of the land is sufficient to induce a sea-breeze effect, the SW. monsoon blows very strongly up to 2,000 to 3,000 feet. Above 3,000 feet the number of observations decreases rapidly, but there is definite indication that the wind tends to veer to west above this height. In the evening (between 5 and 6 p.m. local time) the sea breeze, though only evidenced by the lightness of the wind near the surface, is found as a north-westerly current between 1,000 and 2,000 feet above the surface. Above this height the wind backs to westward.

At first sight it would appear that the strength of the south-westerly wind in the morning was due to the local land breeze reinforcing the natural trend of the wind induced by the pressure gradient, but that this is not the case may be seen from Table IV.

In the first two rows of this table are given mean sea and air temperatures observed by ships in the open sea between longitudes 44° E. and 46° E. to northward of Berbera. In other rows are

TABLE II.—AVERAGE WIND SPEED AT BERBERA

Month \ Hour	1	2	3	4	5	6	7	8	9	10	11	12
											mi./hr.	
January ..	4·8	4·2	4·1	3·8	4·0	4·0	4·3	4·2	3·8	4·6	8·2	11·8
February ..	2·7	2·5	2·9	2·4	2·7	3·2	3·6	3·1	2·7	4·7	8·1	11·5
March ..	2·8	2·6	2·4	2·3	2·2	1·9	2·3	2·1	3·3	6·0	9·8	13·3
April ..	3·1	3·3	3·4	3·5	3·5	3·7	3·3	3·3	4·7	7·6	10·1	12·3
May ..	3·1	3·5	3·4	3·2	3·4	3·4	3·1	3·4	6·2	9·6	12·4	13·5
June ..	9·5	12·0	14·4	15·8	16·3	16·3	17·6	21·7	25·2	24·1	21·2	18·9
July ..	17·1	19·9	23·1	23·9	25·2	26·8	28·6	31·9	34·1	33·0	28·6	23·7
August ..	14·2	16·9	18·4	19·5	21·0	23·0	25·0	28·8	31·8	30·5	25·4	20·7
September	6·3	6·3	6·8	7·1	7·8	7·8	9·1	11·0	14·7	16·6	16·5	14·9
October ..	3·7	4·2	4·4	4·9	5·7	6·0	5·9	5·3	4·0	6·4	9·9	11·9
November ..	4·5	5·3	5·6	6·1	6·9	7·2	8·0	7·1	5·4	6·2	10·5	13·8
December ..	4·5	4·0	4·4	5·3	6·0	6·5	7·0	6·7	5·4	5·7	9·1	12·7
Year ..	6·4	7·1	7·8	8·1	8·7	9·1	9·8	10·7	11·8	12·9	14·1	14·9

TABLE III.—RESULTANT WIND SPEED AND DIRECTION

Month \ Hour	1	2	3	4	5	6	7	8	9	10	11	Noon 12
Jan. °	99	118	132	146	152	155	155	153	133	57	1	6
mi./hr.	3·1	2·4	2·6	2·2	2·7	2·9	2·9	2·7	1·9	1·3	5·6	10·4
Feb. °	101	165	172	184	183	194	184	185	217	320	336	356
mi./hr.	1·1	1·1	1·5	1·4	2·1	2·6	3·0	2·2	1·5	2·6	6·9	10·2
Mar. °	333	360	293	270	270	254	217	297	24	15	22	31
mi./hr.	0·7	0·5	0·8	0·6	0·6	0·7	0·5	0·2	1·0	4·6	8·7	12·2
Apl. °	295	293	270	249	242	225	230	267	301	334	351	8
mi./hr.	1·7	1·5	1·4	1·7	1·9	1·8	1·6	1·7	2·9	6·4	8·6	10·4
May °	240	231	209	198	185	190	172	159	285	343	355	359
mi./hr.	1·4	1·3	1·8	1·3	1·2	1·7	1·4	0·9	1·1	4·9	8·9	11·3
June °	212	206	206	206	206	204	202	204	211	220	231	253
mi./hr.	8·2	10·8	13·6	14·3	15·2	15·6	16·9	20·4	23·8	22·0	17·5	12·7
July °	209	205	204	204	204	204	207	209	212	214	221	232
mi./hr.	15·9	18·9	22·0	23·0	24·7	25·9	27·6	30·9	33·6	32·3	27·6	22·0
Aug. °	219	219	213	211	210	209	209	211	213	219	233	253
mi./hr.	13·1	15·0	17·1	18·3	19·9	22·2	24·1	27·9	31·0	29·6	24·0	17·8
Sept. °	222	215	209	214	212	202	201	205	209	221	254	291
mi./hr.	2·6	3·3	4·1	5·2	6·5	6·6	8·0	10·0	12·5	12·6	8·7	7·9
Oct. °	171	176	168	177	180	175	170	166	155	328	347	355
mi./hr.	1·3	1·5	2·4	3·9	4·7	5·2	5·2	4·5	1·7	3·1	8·1	10·6
Nov. °	185	183	185	181	174	169	165	160	148	52	10	7
mi./hr.	3·3	4·0	4·8	5·5	6·1	6·6	7·4	6·6	3·6	3·4	8·5	12·5
Dec. °	145	160	168	169	169	168	168	162	154	83	17	7
mi./hr.	3·3	3·3	3·8	4·8	5·6	5·8	6·4	6·0	4·1	2·3	7·3	11·8
Year °	206	204	202	201	199	198	197	200	208	227	282	326
mi./hr.	3·7	4·7	5·9	6·6	7·2	7·8	8·4	9·0	8·9	6·7	5·0	6·7

—Based on means for the period May 1931–April 1933.

13	14	15	16	17	18	19	20	21	22	23	24	Mean	No. of Days
14·5	16·5	17·5	17·8	17·4	16·4	14·7	13·1	11·3	9·4	7·6	5·7	9·3	62
14·6	16·5	17·4	17·7	17·4	16·6	15·4	13·3	10·8	9·0	6·0	3·8	8·7	43
16·3	18·2	19·2	19·7	19·5	18·1	16·4	14·2	11·1	7·7	4·7	3·6	9·2	60
14·7	16·7	17·7	17·8	17·9	16·7	14·2	10·6	7·1	4·2	2·8	3·0	8·6	60
14·6	15·6	15·4	14·2	12·9	10·9	9·5	7·5	6·0	4·2	3·0	3·4	7·7	46
16·2	13·8	13·0	12·2	10·8	8·4	6·4	4·7	5·5	6·5	7·7	8·8	13·6	60
19·0	16·6	14·8	13·7	10·2	7·6	6·3	6·0	8·9	11·9	13·5	14·8	19·1	62
17·7	16·1	14·6	12·5	9·6	8·0	6·0	5·3	4·6	7·3	10·6	12·5	16·7	62
14·1	14·3	13·7	12·4	9·6	6·8	4·9	4·1	4·0	4·4	4·8	4·9	9·3	60
13·4	14·2	14·6	13·6	12·7	11·3	9·2	7·1	5·1	3·6	3·6	3·6	7·7	62
15·6	17·0	17·4	17·2	16·5	15·0	13·3	11·5	9·0	6·3	5·2	4·3	9·8	59
15·3	16·9	17·5	17·6	17·0	15·9	14·5	13·0	10·4	8·2	6·3	4·8	9·8	62
15·5	16·0	16·1	15·5	14·3	12·6	10·9	9·2	7·8	6·9	6·3	6·1	10·8	698

—Based on tabulations over the period May 1931–April 1933.

13	14	15	16	17	18	19	20	21	22	23	Midnight 24	Means	Hour / Month
11	17	22	25	29	37	51	60	65	69	76	85	44	° Jan.
13·7	16·1	17·2	17·4	17·3	16·2	14·5	13·0	11·1	9·1	7·1	4·7	6·5	mi./hr.
9	18	22	29	35	46	57	63	66	70	75	79	38	° Feb.
13·3	15·4	16·4	16·9	17·1	16·2	15·3	13·1	10·6	8·5	5·5	2·8	5·9	mi./hr.
40	48	53	59	65	69	75	78	78	78	79	32	56	° Mar.
14·7	16·2	17·4	17·8	17·5	16·0	14·1	12·4	9·6	6·3	3·2	0·9	6·8	mi./hr.
28	41	50	56	63	69	78	84	91	90	315	297	44	° Apr.
12·1	13·7	15·5	15·8	15·7	14·7	12·5	9·2	5·0	1·9	0·3	1·1	4·6	mi./hr.
3	12	22	33	40	47	50	59	51	52	69	219	24	° May
13·1	14·1	14·3	13·4	12·6	10·6	8·8	6·1	5·1	2·8	0·9	1·3	4·4	mi./hr.
275	298	328	353	13	42	73	111	189	202	212	213	221	° June
9·5	8·0	8·2	8·1	7·5	4·6	3·0	1·4	2·5	4·0	5·2	6·9	7·8	mi./hr.
245	263	290	307	291	222	203	203	208	213	215	211	216	° July
15·6	12·1	9·2	6·9	3·0	2·4	3·6	4·6	7·1	10·4	11·9	13·4	15·8	mi./hr.
281	309	325	337	346	356	270	227	214	223	222	219	229	° Aug.
14·2	13·3	12·4	10·1	7·3	2·7	0·4	1·8	3·4	5·2	8·6	11·1	11·7	mi./hr.
325	344	356	4	20	45	57	65	68	102	142	180	264	° Sept.
10·1	12·4	12·5	10·5	7·9	5·1	3·8	3·1	2·4	1·4	1·1	1·2	1·8	mi./hr.
359	5	12	20	31	42	55	67	75	121	160	159	31	° Oct.
12·7	13·5	14·0	13·1	12·0	10·9	9·0	6·4	3·9	1·8	1·5	1·4	3·3	mi./hr.
11	18	23	27	35	46	58	65	73	89	122	171	57	° Nov.
15·0	16·6	17·0	16·9	16·3	14·8	13·0	11·3	8·7	5·2	2·8	2·4	5·6	mi./hr.
13	19	23	27	33	45	55	64	72	78	96	126	54	° Dec.
14·4	16·3	17·3	17·6	16·7	15·7	14·4	12·6	10·0	7·8	5·5	3·4	5·7	mi./hr.
351	5	15	25	35	49	62	69	80	101	155	193	52	° Year
9·1	11·1	12·3	12·3	11·6	10·2	8·6	7·0	4·8	2·7	1·9	2·7	0·4	mi./hr.

TABLE IV.—SEASONAL VARIATION OF TEMPERATURE (°F.) OVER AND ON THE SHORES OF THE GULF OF ADEN

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Gulf of Aden.												
(Mean air)..	77	78	80	82	86	87	85	84	86	84	81	78
(Mean sea)..	77	77	79	82	85	86	81	81	84	84	81	78
Mean daily maximum.												
Berbera ..	82·4	83·4	85·4	88·2	95·4	106·2	105·3	104·6	101·3	91·3	86·5	84·6
Sheikh ..	70·1	73·9	77·3	80·2	81·7	84·4	84·2	83·7	83·4	78·7	72·8	67·9
Diff. (Berbera-Sheikh).	12·3	9·5	8·1	8·0	13·7	21·8	21·1	20·9	16·9	12·6	13·7	16·7
Mean daily minimum.												
Berbera ..	69·7	71·5	74·9	76·7	80·2	87·5	87·8	88·1	84·0	77·2	72·2	69·3
Sheikh ..	49·6	50·2	53·8	57·3	61·5	63·8	62·7	62·3	62·3	53·4	48·9	51·8
Diff. (Berbera-Sheikh).	20·1	21·3	21·1	19·4	18·7	23·7	25·1	25·8	21·7	23·8	23·3	17·5
Perim ..	73	74	76	79	82	84	85	84	84	81	77	75

given the daily mean maximum and mean minimum temperatures at Berbera and at Sheikh (lat. 9° 50′ N., long. 45° 16′ E., i.e. some 50 miles south of Berbera) at a height of 4,800 feet. The means for these two latter places are for the years 1928 to 1932 and so are strictly comparable. There are, therefore, given the differences which may be considered to be quite representative. In the case of the sea observations the period is not synchronous with that for Berbera and Sheikh, but the comparison of the different sets of figures will be tolerably satisfactory.

On comparing the figures of this table we see that the mean daily maximum temperature at Berbera is always greater than the mean air temperature over the sea, so that from temperature considerations we should expect that there would in all months be a tendency for the wind to blow on shore during the hot hours of the day. On the other hand, while the mean minimum temperature is *lower* than the mean air temperature over the sea during the period from September to May, in June, July and August the air temperature at Berbera is on the average *higher* than the air temperature over the sea at all times of the day and still more so than the temperature of the sea surface. From this it is to be expected that in the former season there will be a land breeze but that there will be no such tendency during the months of the SW. monsoon.

The comparisons between Berbera and Sheikh are also interesting when it is remembered that the dry adiabatic lapse for the height interval of 4,800 feet is about 26° F. During the NE. monsoon there is evidently considerable warming during the day between Berbera and Sheikh, and if the night drain of air extends from Sheikh to Berbera, the motion is evidently slow enough to allow some further cooling during the process.

The fact that the surface temperature at Berbera during the SW. monsoon does not fall below that over the sea at nights, implies that there can be no thermal effect between sea and land to induce a flow of air from south-westward and, moreover,

the surface observations of ships at sea in the Gulf of Aden show in general a south-westerly wind during that season ; so it may be concluded that the strong south-westerly winds of early morning up to 3,000 feet are part of the general circulation rather than a purely local feature.

The direct horizontal path of this wind is, however, barred to southward and south-westward by the mountains. While the temperatures at Sheikh and Berbera do not preclude the possibility of the air composing this south-westerly current having descended from the summits of the mountains (and indeed a foehn effect would form a satisfactory explanation of the exceedingly high temperatures experienced at Berbera), the upper winds between 4,000 and 6,000 feet are westerly rather than south-westerly.

Comparing the surface winds with the upper-air wind roses, it is somewhat surprising to find to what great heights the land breeze extends. In Fig. 7 the NE. monsoon can be clearly seen blowing at 3,000 feet and above but even at 1,500 feet it is much decreased in velocity by the drain of air from the land. From a mere inspection of an anemogram such as that shown in Fig. 5, it would not have been anticipated that the effects of the seaward drain would have reached higher than some 100 or 200 feet above the surface, a height to which a normal surface inversion of temperature on a clear night would be expected to reach.

The suppression of the land breeze from March to May, to which reference has been made earlier, is explicable from a study of the temperatures given in Table IV. During the winter months the air temperature at Berbera during the night falls decidedly below the air and sea temperature in the Gulf of Aden and a land breeze naturally develops. As the land areas warm up in spring, however, the difference becomes less and the land breeze becomes less marked finally failing altogether. In the last row of Table IV are given the mean daily minimum temperatures at Perim, the comparison of which with the Berbera temperatures further emphasises this point.

It has been pointed out above that the magnitude of the diurnal variation of the winds at Berbera, both at the surface and up to 3,000 feet, during the season of the SW. monsoon was greater than would normally be expected on the hypothesis of a simple land and sea breeze being superposed on the south-westerly current. It was thought that in this locality there might be some factor which was causing the diurnal variation to be magnified and so an examination was made of the diurnal variation of temperature and wind in July over the sea in the square contained by latitudes 12° and 13° N., longitudes 46° and 47° E. As would be expected, there is little or no diurnal variation of air temperature in that position. The wind, however, shows a very appreciable difference between day and night, as is shown by Table V.

TABLE V.—DIURNAL VARIATION OF WIND IN JULY IN LAT. 12° TO 13°N., LONG. 46° TO 47°E.

Hour	Mdt.	4	8	12	16	20
Resultant direction ..	199°	209°	218°	222°	226°	218°
Resultant speed (mi./hr.)	6·8	12·5	13·5	19·0	13·0	2·8
Number of obs. ..	35	27	30	17	22	24

This variation is illustrated in Fig. 8, which is drawn in a similar manner to Fig. 6. The range amounts to as much as 12 miles per hour. Now the centre of this square is about 60 nautical miles from the coast of Arabia and about 110 from the

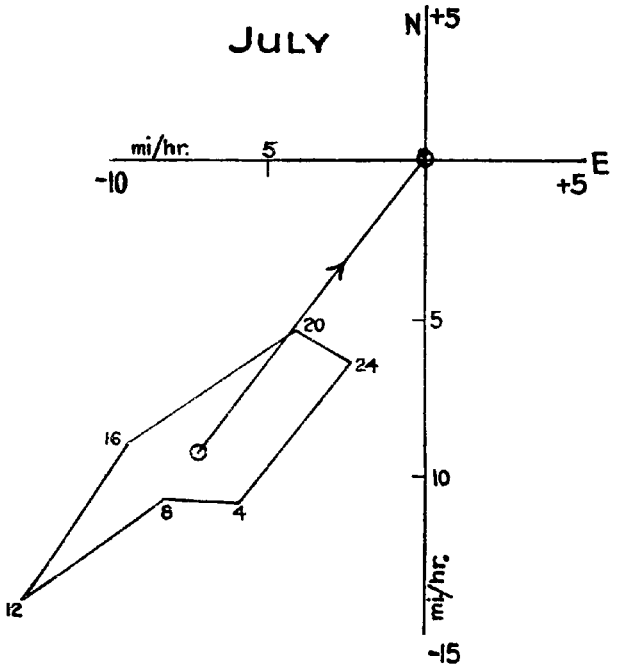


FIG. 8.—Diurnal variation of resultant wind in the Gulf of Aden.

coast of Somaliland, distances at which the effects of the land and sea breezes are normally almost negligible. It is, moreover, notable that the curve of Fig. 8 is lagged about 3 to 4 hours behind the June to August curve shown on Fig. 6. Thus it is clear that the diurnal variation of wind over the Gulf of Aden in the SW. monsoon months is not merely a local phenomenon confined to the coast lines and a few miles on either side, but is a much larger phenomenon extending over a considerable area and reaching to considerable heights.

To complete the picture, certain inferences as to the thermal structure of the monsoons at Berbera may be drawn from the anemograms shown in Figs. 4 and 5 :—

(i) In the season of the SW. monsoon the off-shore wind blows in a succession of gusts and lulls, about 8 to 12 such

gusts occurring in an hour. The surface wind speed being about 30 miles per hour and the velocity of the free wind being assumed to be about 45 miles per hour, it is readily calculated that the average horizontal distance between successive gusts is of the order of $4\frac{1}{2}$ miles. If these gusts are due to the descent of air around convective cells such as have been pictured elsewhere[2], in a regular polygonal pattern the distance between centres of consecutive cells should be about three times the depth of the unstable fluid. These cells, are, however, probably elongated and hence this factor of 3 is probably too large. It would therefore seem that the gustiness of the off-shore wind is compatible with convection taking place up to a height of some 4,000 to 7,000 feet. From the consideration that the air has flowed over a mountain range of about 4,000 feet height, such a layer of instability is to be expected. Indeed, it is to be anticipated that aeroplanes operating in this region during the SW. monsoon will encounter very bumpy conditions.

The afternoon wind in July, however, has characteristics which are not associated with convection, but with the breaking down of an inversion and a very stable lapse rate. As has been pointed out above, the air temperature of the off-shore wind is greatly above that of the sea surface in July and even the air temperatures of ships at sea average 4 degrees higher than the sea temperature. During the SW. monsoon, therefore, it is to be expected that an inversion of temperature lies over a great part of the Gulf of Aden and that the air flow is free of the larger-scale eddies. From the anemograms of Berbera it would seem that when the on-shore breeze sets in it brings this stable air over the coast line.

(ii) During the months of the NE. monsoon the anemograph record of the off-shore wind shows very marked indications of an inversion forming during the early part of the night and breaking down, owing to the intensity of the wind gradient, during the latter part of the night.[3] The on-shore wind from NE. by day is definitely of an unstable type, but in this case the gusts are far more frequent in their occurrence than during the SW. monsoon and even when consideration is taken of the lower wind speed, the gusts are considerably less far apart horizontally than in the case of the off-shore wind of the SW. monsoon ; indeed, a very rough estimate puts them at less than $1\frac{1}{2}$ miles apart, which (from the previous argument) would make the height of the unstable layer 2,500 to 1,500 feet.

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[2] The structure of wind over level country. *London, Meteor. Off. Geophys. Mem.* No. 54.

[3] Durst, C. S. The breakdown of steep wind gradients in inversions. *Q.J. R. Meteor. Soc.*, **59**, 1933, p. 131.

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